

Name of Technology (256 char) Brief description of the technology (1024)	Laser	Phasemeter system	Alignment Sensing	Telescope	Gravitational Reference Sensor	Thrusters
	LISA laser requires power of $P=2W$ in a linear polarized, single frequency, single spatial mode. It requires fast actuators ($BW > 10kHz$) for intensity and frequency stabilization to enable laser phase locking and relative intensity noise of $<10^{-6}/rtHz$. Lifetime > 10 yrs. Shotnoise limited at 1mW laser power above 2MHz. Potential laser types: Diode pumped solid state lasers Diode pumped fiber lasers Extended Cavity diode lasers	The phasemeter measures the phase of laser beat signals with $ucycl/rtHz$ sensitivity. It is the main interferometry signal for LISA. The phasemeter consists of a fast photo receiver which detects the beat signal, an ADC which digitizes the laser beat signal, and a digital signal processing board which processes the digitized signals.	Alignment sensing in interferometric space missions like LISA or formation flying requires maintaining the alignment between the individual spacecraft. This is done with differential wavefront sensing between a local and the received laser beam. The missing key element is a four element fast, non-dispersive photo detector.	LISA and also formation flying missions require telescopes to exchange laser fields for position and alignment sensing. The requirements for these telescopes include unusual length and alignment stability requirements at the pm and mrad level. Scattered light from within the telescope could affect the interferometric measurements.	Gravitational Wave detectors (LISA and LISA follow-on missions) as well as other fundamental physics missions require gravitational reference sensors. For LISA, the residual acceleration of the GRS has to be in the sub-fg/rtHz range. ESA has developed a gravitational reference sensor for the LISA pathfinder and will test it in flight in the upcoming years. This reference sensor consists of a proof mass in an electro-static housing. Key technologies include magnetic cleanliness, charge mitigation, gas damping, thermal noise, and actuator noise. Gravitational reference sensors are completely missing in the TABS with the exception of the atomic interferometer.	Thrusters for in-space operation with very low noise, tunable thrust, long lifetime (> 5 years) are required for LISA. LISA follow-on missions, and for formation flying missions. LISA needs low noise with less thrust ($\mu N/rtHz$ and $100\mu N$ thrust). The requirements for formation flying missions are mission specific but require more thrust but can also tolerate more noise compared to LISA.
Goals and Objectives (1024)	The goal is to reach TRL 6 in 2015 with a laser system that meets LISA requirements. Frequency Comb has nothing to do with the LISA laser. Low noise or Ultra-low noise is not necessary because of active stabilization. The laser is at the beginning of the optical train and the required modulators, fibers, optical components, etc depend on the laser type. A change to a different laser system later could require a complete redesign of large portions of the optical system.	The goal is to reach TRL 6 by 2015 with the phasemeter system that meets LISA requirements. This system is essential to support tests of other subsystems at the $ucycl/rtHz$ level and should be developed as soon as possible. Should be developed with Alignment sensing photodetector.	The goal is to reach TRL 6 by 2016 with the alignment sensing system. It should be developed together with the phasemeter system. Understanding the capabilities and the sensitivity of the alignment sensing system enables more targeted technology developments for LISA and allows to develop realistic designs for formation flying mission.	Athermal telescope designs have to be developed to meet the length and alignment requirements. Materials have to be tested for creep at the pm/nrad level. Study ways to predict and reduce the effects of back scatter on the interferometry.	The initial goal has to be the support of the LISA pathfinder and to import the technology to learn as much as possible from the pathfinder. This could raise the TRL well above 6 immediately. Future R&D in this direction has to depend on the outcome of the pathfinder mission. The lessons learned should help to evaluate how far this technology can be pushed or if radically new ideas should be investigated.	TRL 6 for colloid thrusters meeting the LISA requirements. Scalability of these and other thrusters to meet formation flying requirements needs to be investigated.
TRL	4 TRL is between 4 and 5. Requires now efforts towards space qualification and testing in relevant environment.	5 The phasemeter has been demonstrated but only with single element photodetectors and most of the components are not space qualified.	4. This might just be testing commercially available quadrant detectors and identifying one that meets the requirements.	4 for length and alignment stability 2 for backscatter.	Pathfinder GRS: TRL > 6	Colloids: TRL 6
Tipping Point (100 words or less)	Laser meeting these requirements exist already. Several designs have reached TRL 4. A focused effort could increase this to TRL 6 or at least identify the issues in a fairly short time.	The main missing elements are the quadrant photodetector and ADC's with low enough timing jitter. A focused effort could solve this problem in a fairly short time.	A survey of the available quadrant detectors and simple tests of the most promising ones might be sufficient to get this to TRL 6.	Length and alignment stability: This requires to build a real LISA telescope and test it. Note that a 40cm telescope is not a gigantic investment but developing the measurement capabilities requires some funding. The coherent backscatter has never been seriously analyzed and an initial minor investment would make a huge difference.	Yes, if NASA can take advantage of the LISA pathfinder.	This should be an ongoing effort
NASA capabilities (100 words)	NASA's capabilities in this area appear to be restricted to testing and space qualification. Commercial laser companies or specialized groups in academia have the expertise and capabilities to collaborate with NASA on this effort.	NASA's does not have the capabilities to develop the individual components alone but could collaborate with industry to design and test them. NASA and some groups in academia have the expertise to test these components and later the entire system.	NASA and several university groups have the capability to test these components. If the currently available components don't meet the requirements, NASA needs to work with industry to improve them. NSF-funded LIGO research could benefit from progress in this area.	NASA has the capability to build a 40cm LISA telescope but the capabilities to measure the length and alignment variation need to be developed. NASA (and many others) could analyze and test the back scatter.	ESA is building it and collaborates with NASA on the pathfinder.	Well within NASA capabilities
Benefit/Ranking	It would allow to define the interfaces between the laser and all other subsystems in LISA. This simplifies and in some cases enables R&D on other important components. The laser system itself would also be useful for other laser interferometric missions such as formation flyers, multiple aperture missions, or Grace-follow on missions. Ranking: iv	The capability to measure noise at the $ucycl/rtHz$ level is essential for the R&D on many other components. Having well tested phasemeter system would enable this work and accelerate the R&D in general. Ranking: iv	Maintaining the relative alignment between multiple components on one spacecraft and between separated spacecraft is essential for LISA and for formation flying missions. Having a sensing system early allows tests of newly developed subsystems and integration tests early on. Ranking: vi	The telescope is another key part of LISA and formation flying missions. Off-axis telescope with additional interferometer to control length and alignment of the components are an alternative but would increase mass and complexity. Ranking: ii	Yes. A gravitational reference sensor with sub fg/rtHz residual acceleration is critical for gravitational wave missions. Making sure that NASA has access to this technology should be one of the top priorities. Ranking: iv	Formation flying would be a game changer. Thrusters are only a part of this. On going effort.
NASA needs/Ranking	LISA and other laser interferometric missions such as formation flying missions, Grace follow-on Ranking: iv	LISA is the main customer but other interferometric space missions are planning to use similar phasemeter. Having a completely characterized system with $ucycl/rtHz$ sensitivity would meet many NASA needs. Ranking: iv	Required for LISA and formation flying missions. Having a completely characterized system with $ucycl/rtHz$ sensitivity would meet many NASA needs. Ranking: iv	Would significantly simplify LISA and formation flying missions. Ranking: iv	LISA and LISA-follow on missions depend on it. Ranking: iii	Formation flyer depend on it. Need for LISA solved with pathfinder demonstration except for lifetime. Ranking: iv
Non-NASA but aerospace needs	Formation flying might have commercial and national security applications in the form of smaller satellite missions. Ranking: iii	Formation flying might have commercial and national security applications in the form of smaller satellite missions. Ranking: iii	Formation flying might have commercial and national security applications in the form of smaller satellite missions. Ranking: iii	Formation flying might have commercial and national security applications in the form of smaller satellite missions. Ranking: iii	No non-NASA needs as far as I know Ranking: i	Formation flying might have commercial and national security applications in the form of smaller satellite missions. Ranking: iii
Non aerospace needs	Non. Non space-qualified lasers which meet the requirements are commercially available. Ranking i	Science and Engineering applications. Ranking: iii	Science and Engineering applications. Ranking: iii	Ranking: i	No non-NASA needs as far as I know Ranking: i	Ranking: i

Technical Risk	The technical risk is low. Several commercial systems exists that meet the requirements except space qualification. No commercial company will space qualify a LISA laser to commercialize it. Ranking ii.	Technical risk is low. The main challenge is to get the temperature dependent dispersion under control. Ranking ii	Technical risk is low. The main challenge is to get the temperature dependent dispersion under control without reducing bandwidth and area to much. Ranking ii	Technical risk for the longitudinal and alignment stability is low. Materials have been tested at the sub-pm level. The main challenge appears to be to develop the capabilities to perform the experiments. Backscatter: No risk. This is an assessment if on-axis telescopes will meet the requirements or if substantial R&D is required to develop an off-axis telescope.	ESA is taking most of the financial risk right now. If the pathfinder reaches the performance, technical risks for NASA are minimal. Ranking: ii (although the definitions for the rankings are not really applicable)	Continuous development. Technical risk low
Sequencing/Timing	Should come as early as possible. The development of many other components depends on the specific laser system. Ranking iv	Should come as early as possible. The development of many other components depends on the availability of a phasemeter with ucycl/rHz sensitivity. Ranking iv	Requires phasemeter. Should start before phasemeter development is finished and should be finished 1-2 years after phasemeter is at TRL 6. Ranking: iv	Length and alignment: The current status is sufficient for planing purposes. Tests on real models should start 2017. Backscatter: Start immediately as small effort Ranking: iv	The timing is set by ESA. Ranking: iv	Continuous development.
Time and Effort to achieve goal	3 year collaboration between industry and NASA. Ranking: iii	3 year collaboration between industry, academia, and NASA. Ranking iv	2 year collaboration between academia and NASA. Ranking iv	3 year academia project Ranking: iv	Effort and time depends on form of collaboration with ESA. Ranking: iv (because of ESA lead)	Continuous development.
Comment from me	Clarifies specs in TABS	Not mentioned	Wavefront sensing in TABS08 is more adaptive optics related and not alignment related. LISA cares mainly about maintaining alignment.	Telescopes for multi-S/C interferometric missions have different requirements than big optical telescopes. This is not reflected in the TABS	I don't think NASA needs to do anything in this area right now except make sure that they know how the LISA pathfinder works. And please forget the atomic interferometry for the next 10 years.	It is essentially covered. Maybe not really in the context of formation flying missions. OK, atomic interferometry is a real near term project compared to the quantum vacuum drive proposed in this TABS...